Technology Brief 2: Solar Cells

A ***solar cell*** is a photovoltaic device that converts solar energy into electricity. The conversion process relies on the ***photovoltaic effect***, which was first reported by 19-year-old Alexandre-Edmond Becquerel in 1839 when he observed that a platinum electrode produced a small current if exposed to light. The photovoltaic effect is often confused with the ***photoelectric effect***; they are interrelated, but not identical (Fig. TF2-1).

The photoelectric effect explains the mechanism responsible for why an electron is ejected by a material in consequence to a photon incident upon its surface [Fig. TF2-1(a)]. For this to happen, the photon energy E (which is governed by its wavelength through $E = hc/\lambda$, with h being Planck's constant and c the velocity of light) has to exceed the binding energy with which the electron is held by the material. For his 1905 quantum-mechanical model of the photoelectric effect, Albert Einstein was awarded the 1921 Nobel Prize in physics.

Whereas a single material is sufficient for the photoelectric effect to occur, at least two adjoining materials with different electronic properties (to form a junction that can support a voltage across it) are needed to establish a ***photovoltaic current*** through an external load [Fig. TF2-1(b)]. Thus, the two effects are governed by the same quantum-mechanical rules associated with how photon energy can be used to liberate electrons away from their hosts, but the followup step of what happens to the liberated electrons is different in the two cases.

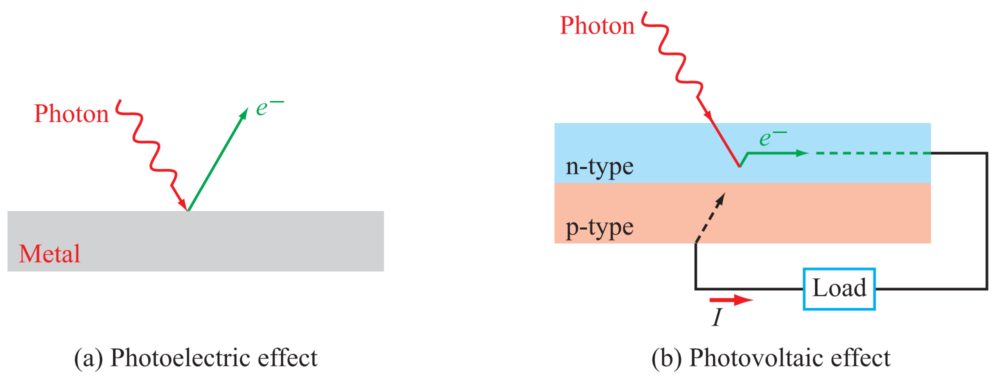

Figure TF2-1: Comparison of photoelectric effect with the photovoltaic effect.

The PV Cell

Today's photovoltaic (PV) cells are made of semiconductor materials. The basic structure of a PV cell consists of a ***p-n junction*** connected to a load (Fig. TF2-2).

Typically, the n-type layer is made of silicon doped with a material that creates an abundance of negatively charged atoms, and the p-type layer also is made of silicon but doped with a different material that creates an abundance of holes (atoms with missing electrons). The combination of the two layers induces an electric field across the junction, so when an incident photon liberates an electron, the electron is swept under the influence of the electric field through the n-layer and out to the external circuit connected to the load.

The ***conversion efficiency*** of a PV cell depends on several factors, including the fraction of the incident light that gets absorbed by the semiconductor material, as opposed to getting reflected by the n-type front surface or transmitted through to the back conducting electrode. To minimize the reflected component, an antireflective coating usually is inserted between the upper glass cover and the n-type layer (Fig. TF2-2).

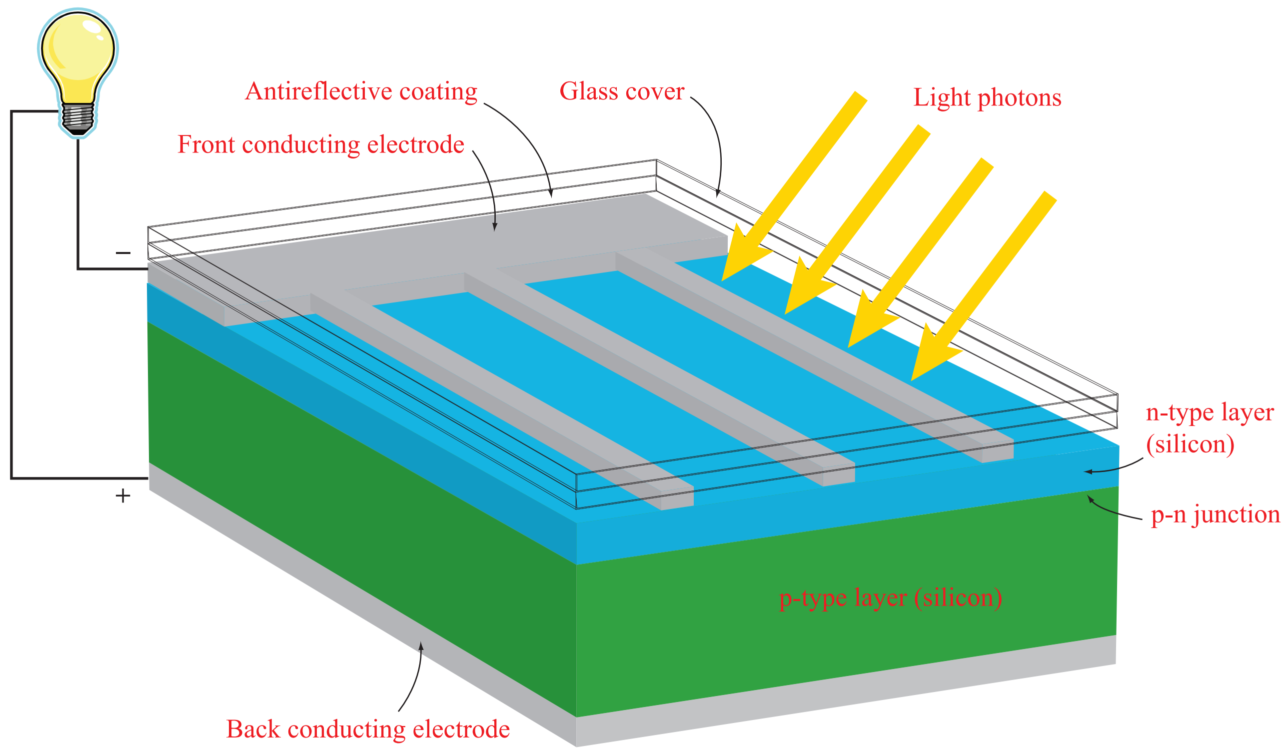

Figure TF2-2: Basic structure of a photovoltaic cell.

The PV cell shown in Fig. TF2-2 is called a ***single-junction cell*** because it contains only one p-n junction. The semiconductor material is characterized by a quantity called its ***band gap energy***, which is the amount of energy needed to free an electron away from its host atom. Hence, for that to occur, the wavelength of the incident photon (which, in turn, defines its energy) has to be such that the photon's energy exceeds the band gap of the material. Solar energy extends over a broad spectrum, so only a fraction of the solar spectrum (photons with energies greater than the band gap) is absorbed by a single-junction material. To overcome this limitation, multiple p-n layers can be cascaded together to form a ***multijunction PV device*** (Fig. TF2-3). The cells usually are arranged such that the top cell has the highest band gap energy, thereby capturing the high-energy (short-wavelength) photons, followed by the cell with the next lower band gap, and so on. The multijunction technique offers an improvement in conversion efficiency of 2–4 times over that of the single-junction cell. However, the fabrication cost is significantly greater as well.

Modules, Arrays, and Systems

A ***photovoltaic module*** consists of multiple PV cells connected together so as to supply electrical power at a specified voltage level, such as 12 or 24 V. The combination of multiple modules generates a ***PV array*** (Fig. TF2-4). The amount of generated power depends on the intensity of the intercepted sunlight, the total area of the module or array, and the

conversion efficiencies of the individual cells. If the PV energy source is to serve multiple functions, it will need to be integrated into an energy management system that includes a dc to ac current converter and batteries to store energy for later use (Fig. TF2-5).

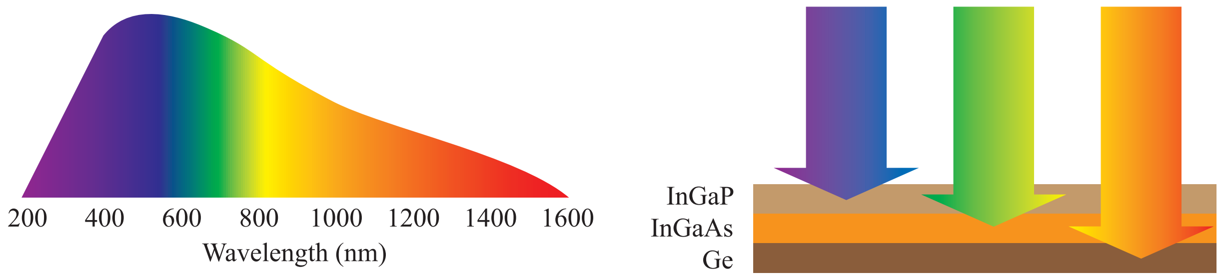

Figure TF2-3: In a multijunction PV device, different layers absorb different parts of the light spectrum.

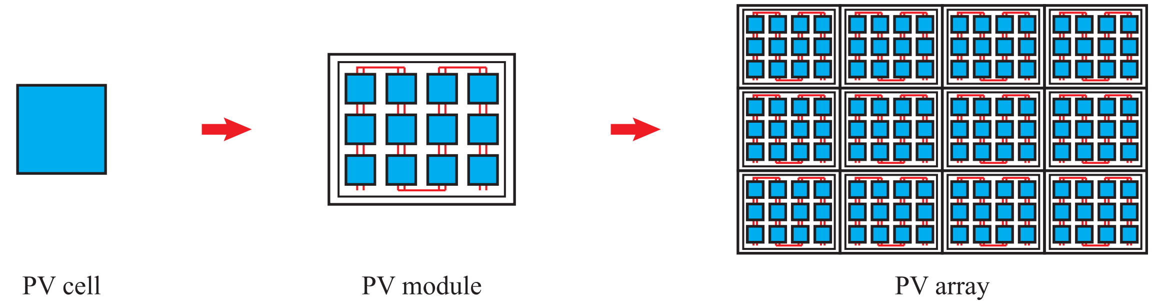

Figure TF2-4: PV cells, modules, and arrays.

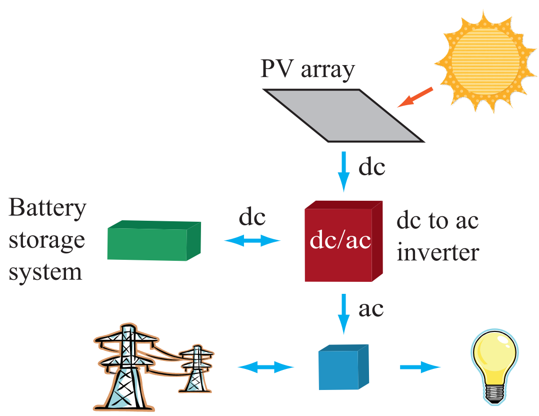

Figure TF2-5: Components of a large-scale photovoltaic system.